ECG Signal Analysis Using Wavelet Transforms

C. Saritha, **V. Sukanya**, **Y. Narasimha Murthy**

Department of Physics and Electronics, S.S.B.N. COLLEGE (Autonomous)
Anantapur – 515 001, Andhrapradesh, India

Abstract. This paper deals with the study of ECG signals using wavelet transform analysis. In the first step an attempt was made to generate ECG waveforms by developing a suitable MATLAB simulator and in the second step, using wavelet transform, the ECG signal was denoised by removing the corresponding wavelet coefficients at higher scales. Then QRS complexes were detected and each complex was used to find the peaks of the individual waves like P and T, and also their deviations.

1 Introduction

The ECG is nothing but the recording of the hearts electrical activity. The deviations in the normal electrical patterns indicate various cardiac disorders. Cardiac cells, in the normal state are electrically polarized. Their inner sides are negatively charged relative to their outer sides. These cardiac cells can lose their normal negativity in a process called depolarization, which is the fundamental electrical activity of the heart. This depolarization is propagated from cell to cell, producing a wave of depolarization that can be transmitted across the entire heart. This wave of depolarization produces a flow of electric current and it can be detected by keeping the electrodes on the surface of the body. Once the depolarization is complete, the cardiac cells are able to restore their normal polarity by a process called re-polarization. This is also sensed by the electrodes [1].

The earlier method of ECG signal analysis was based on time domain method. But this is not always sufficient to study all the features of ECG signals. So, the frequency representation of a signal is required. To accomplish this, FFT (Fast Fourier Transform) technique is applied. But the unavoidable limitation of this FFT is that the technique failed to provide the information regarding the exact location of frequency components in time. As the frequency content of the

ECG varies in time, the need for an accurate description of the ECG frequency contents according to their location in time is essential. This justifies the use of time frequency representation in quantitative electro cardiology.

The immediate tool available for this purpose is the Short Term Fourier Transform (STFT). But the major draw-back of this STFT is that its time frequency precision is not optimal. Hence we opt a more suitable technique to overcome this drawback. Among the various time frequency transformations the wavelet transformation is found to be simple and more valuable [2].

The wavelet transformation is based on a set of analyzing wavelets allowing the decomposition of ECG signal in a set of coefficients. Each analyzing wavelet has its own time duration, time location and frequency band. The wavelet coefficient resulting from the wavelet transformation corresponds to a measurement of the ECG components in this time segment and frequency band.

2 Theory

The ECG records the electrical activity of the heart, where each heart beat is displayed as a series of electrical waves characterized by peaks and valleys. Any ECG gives two kinds of information. One, the duration of the electrical wave crossing the heart which in turn decides whether the electrical activity is normal or slow or irregular and the second is the amount of electrical activity passing through the heart muscle which enables to find whether the parts of the heart are too large or overworked.

Normally, the frequency range of an ECG signal is of 0.05–100 Hz and its dynamic range – of 1–10 mV. The ECG signal is characterized by five peaks and valleys labelled by the letters P, Q, R, S, T. In some cases we also use another peak called U. The performance of ECG analyzing system depends mainly on the accurate and reliable detection of the QRS complex, as well as T- and P-waves. The P-wave represents the activation of the upper chambers of the heart, the atria, while the QRS complex and T-wave represent the excitation of the ventricles or the lower chamber of the heart. The detection of the QRS complex is the most important task in automatic ECG signal analysis. Once the QRS complex has been identified a more detailed examination of ECG signal including the heart rate, the ST segment *etc.* can be performed [3].

In the normal sinus rhythm (normal state of the heart) the P-R interval is in the range of 0.12 to 0.2 seconds. The QRS interval is from 0.04 to 0.12 seconds. The Q-T interval is less than 0.42 seconds and the normal rate of the heart is from 60 to 100 beats per minute. So, from the recorded shape of the ECG, we can say whether the heart activity is normal or abnormal.

The electrocardiogram is a graphic recording or display of the time variant voltages produced by the myocardium during the cardiac cycle. The P-, QRS- and

T-waves reflect the rhythmic electrical depolarization and repolarization of the myocardium associated with the contractions of the atria and ventricles. This ECG is used clinically in diagnosing various abnormalities and conditions associated with the heart.

Amplitude	P-wave	— 0.25 mV
	R-wave	— 1.60 mV
	Q-wave	— 25% R wave
	T-wave	— 0.1 to 0.5 mV

Duration	P-R interval	: 0.12 to 0.20 s
	Q-T interval	: 0.35 to 0.44 s
	S-T interval	: 0.05 to 0.15 s
	P-wave interval	: 0.11 s
	QRS interval	: 0.09 s

The normal value of heart beat lies in the range of 60 to 100 beats/minute. A slower rate than this is called bradycardia (Slow heart) and a higher rate is called tachycardia (Fast heart). If the cycles are not evenly spaced, an arrhythmia may be indicated. If the P-R interval is greater than 0.2 seconds, it may suggest blockage of the AV node.

- Certain disorders, involving heart valves cannot be diagnosed from ECG. Other diagnostic techniques such as angiography and echocardiography can provide information not available in ECG.

- Each action potential in the heart originates near the top of the right atrium at a point called the pacemaker or sinoatrial (SA) node.

- The wave generated by action potential, terminates at a point near the center of the heart, called the atrioventricular (AV) node.

The horizontal segment of this waveform preceding the P-wave is designated as the baseline or the isopotential line. The P-wave represents depolarization of the atrial musculature. The QRS complex is the combined result of the repolarization of the atria and depolarization of the ventricles, which occur almost simultaneously.

The T-wave is the wave of ventricular repolarization, where as the U-wave, if present is generally believed to be the result of after potentials in the ventricular muscle. So, the duration amplitude and morphology of the QRS complex is useful in diagnosing cardiac arrhythmias, conduction abnormalities, ventricular hypertrophy, myocardial infection and other disease states [4].
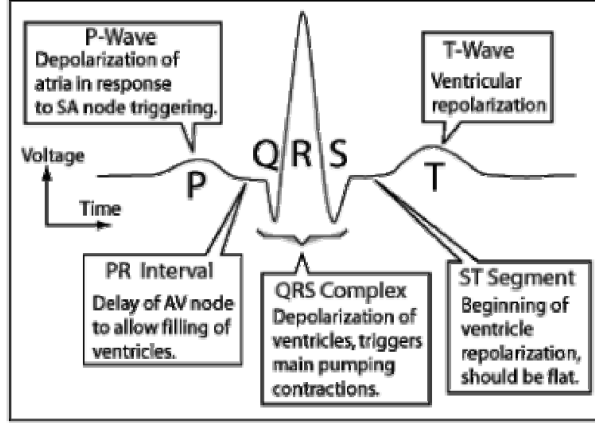
Figure 1. The normal ECG waveform.

3 Materials and Methods

3.1 Wavelet transform

The wavelet transform is a convolution of the wavelet function $\psi(t)$ with the signal $x(t)$. Orthonormal dyadic discrete wavelets are associated with scaling functions $\phi(t)$. The scaling function can be convolved with the signal to produce approximation coefficients S. The discrete wavelet transform (DWT) can be written as

$$T_{m,n} = \int\limits_{-\infty}^{\infty} x(t)\psi_{m,n}(t)dt. \tag{1}$$

By choosing an orthonormal wavelet basis $\psi_{m,n}(t)$ we can reconstruct the original [5]. The approximation coefficient of the signal at the scale m and location n can be written as

$$S_{m,n} = \int\limits_{-\infty}^{\infty} x(t)\phi_{m,n}(t)dt. \tag{2}$$

But the discrete input signal is of finite length N. So the range of scales that can be investigated is $0 < m < M$. Hence a discrete approximation of the signal can be written as

$$x_0(t) = x_M(t) + \sum_{m=1}^{M} d_m(t), \tag{3}$$

where the mean signal approximation at scale M is $x_M(t) = S_{M,n}\phi_{M,n}(t)$ and detail signal approximation corresponding to scale m, for finite length signal is

given by

$$d_m(t) = \sum_{n=0}^{M-m} T_{m,n} \psi_{m,n}(t). \tag{4}$$

The signal approximation at a specific scale is a combination of the approximation and detail at the next lower scale.

$$x_m(t) = x_{m-1}(t) - d_m(t) \tag{5}$$

In the present work Daubechies [6] wavelet is chosen although the Daubechies algorithm is conceptually more complex and has a slightly complicated computations, yet this algorithm picks up minute detail that is missed by other wavelet algorithms, like Haar wavelet algorithm. Even if a signal is not represented well by one member of the Daubechies family, it may still be efficiently represented by another.

3.2 Wavelet analysis

The wavelet analysis of ECG signal is performed using MATLAB software. MATLAB is a high performance; interactive system which allows to solve many technical computing problems. The MATLAB software package is provided with wavelet tool box. It is a collection of functions built on the MATLAB technical computing environment. It provides tools for the analysis and synthesis of signals and images using wavelets and wavelet packets within the MATLAB domain.

The normal ECG wave form and the waveforms with abnormalities are shown in Figures 2,3 and 4.
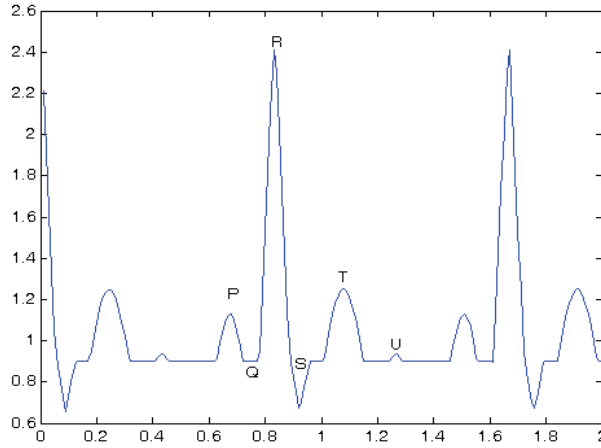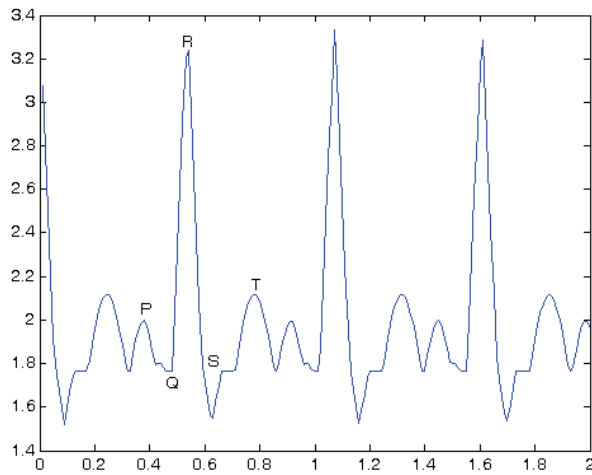

Figure 2. Normal sinus rhythm.

Figure 3. Sinus tachycardia.

We have considered in Section 2 the commonly known abnormalities and the waveforms corresponding to these abnormalities are loaded in to wavelet tool box and the coefficients' plots are compared with those of Normal ECG. Different standard wavelets have been tried and Daubechies wavelet ('db10') was found to be the most suitable for the analysis of ECG signals. Different abnormalities result in different changes in the coefficients.

From the results of the wavelet toolbox the following observations were made and shown in Table 1.
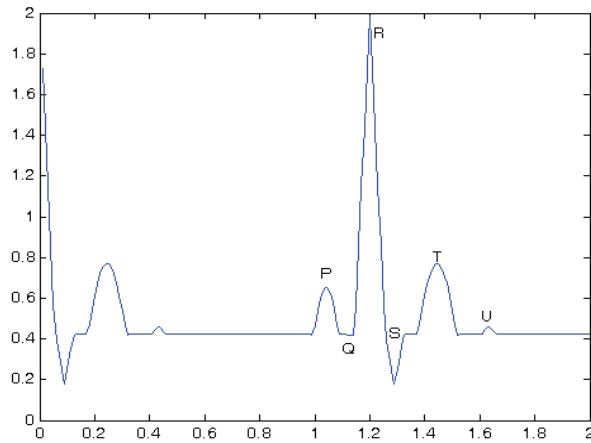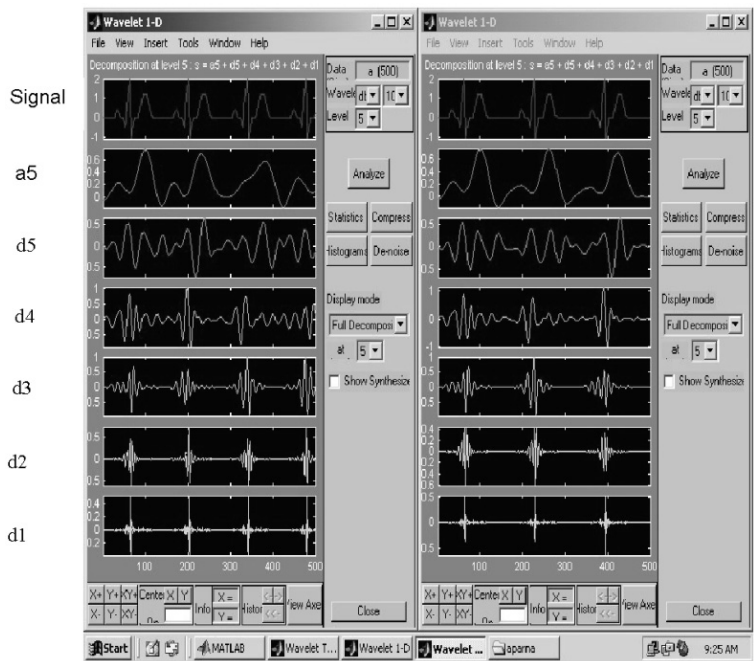

Figure 4. Sinus bradycardia.

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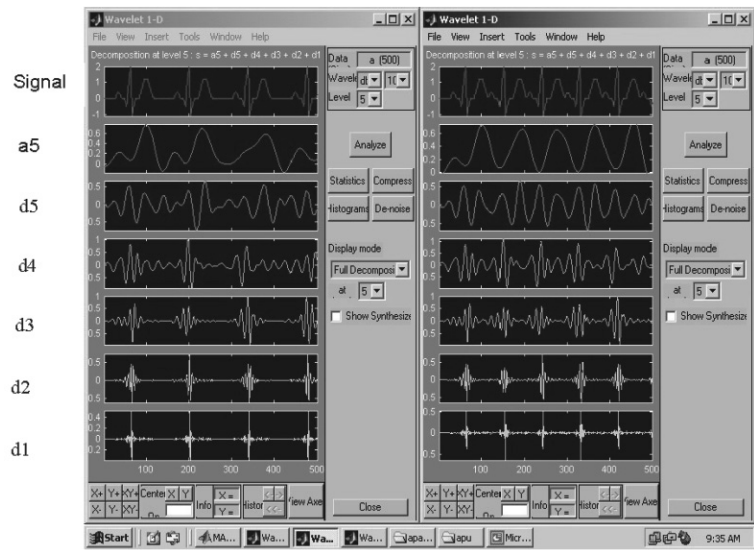Figure 5. Comparison of abnormality "bradycardia" with normal ECG wave.

Figure 6. Comparison of abnormality "tachycardia" with normal ECG wave.

Figure 7. Comparison of abnormality "hyperkalemia" with normal ECG wave.

Figure 8. Comparison of abnormality "hyperkalemia" with normal ECG wave.

Table 1. Various abnormalities and their characteristic features

S. No.	Name of abnormality	Characteristic features
1	Dextrocardia	Inverted P-wave
2	Tachycardia	R-R interval < 0.6 s
3	Bradycardia	R-R interval > 1 s
4	Hyperkalemia	Tall T-wave and absence of P-wave
5	Myocardial ischaemia	Inverted T-wave
6	Hypercalcaemia	QRS interval < 0.1 s
7	Sinoatrial block	Complete drop out of a cardiac cycle
8	Sudden cardiac death	Irregular ECG

4 Results and Discussion

One of the crucial steps in the ECG analysis is to accurately detect the different waves forming the entire cardiac cycle. Most of the studies based around wavelet transformation identify 99.8% of ECG waveforms [7]. Especially the wavelet transformation is worth investigating in P- and T-wave recognition. Some authors use wavelet technique for identification of the ECG changes resulting from acute coronary artery occlusion and are able to identify specific detailed time frequency components of ECG signal, which are sensitive to transient ischemia and eventual restoration of electrophysiological function of the myocardial tissue.

The practical benefit of the wavelet based ECG approach is that T-wave abnormalities can be assessed without the need for T-wave end point identification. The wavelet transformation is a new promising technique in non-invasive electro cardiology providing improved methods for late potential detection. We can observe that the peaks of QRS complexes flatten and P- and T-waves containing lower frequencies become more visible. At the same time we can also find that details at lower scales constitutes the higher frequencies of the signal. The benefit of the wavelet transformation lies in its capacity to highlight the details of the ECG signal with optimal time frequency resolutions [8].

5 Conclusions

Since the application of wavelet transformation in electro cardiology is relatively new field of research, many methodological aspects (Choice of the mother wavelet, values of the scale parameters) of the wavelet technique will require further investigations in order to improve the clinical usefulness of this novel signal processing technique. Simultaneously diagnostic and prognostic significance of wavelet techniques in various fields of electro cardiology needs to be established in large clinical studies.

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